Advanced Oil Recovery Technologies for Improved Recovery from Slope Basin Clastic Reservoirs

Bill Weiss
Petroleum Recovery Research Center
New Mexico Tech
Socorro, NM 87801

Abstract

Advanced oil recovery technologies applied to the Nash Draw Brushy Canyon Pool revealed that the initial reservoir characterization was too simplistic. The field discovered in 1992, currently produces 458 BOE/day from a deep-water marine turbidite sandstone reservoir in the Delaware Mountain Group at 6800 ft.

A new log interpretation method tuned with core analyses demonstrated that the initial OOIP estimate was too large. This log interpretation method found oil behind-pipe and reduced completion costs.

Geostatistical maps based on well parameters targeted zones of high oil saturation between wells, but were of little value when extrapolating outside the area of well control. A high resolution, 3D seismic survey designed for the thin-bedded turbidite sands provided the information to extrapolate beyond the area of well control. Computational intelligence applied to seismic attributes targeted sweet spots, mapped as hydrocarbon pore volume.

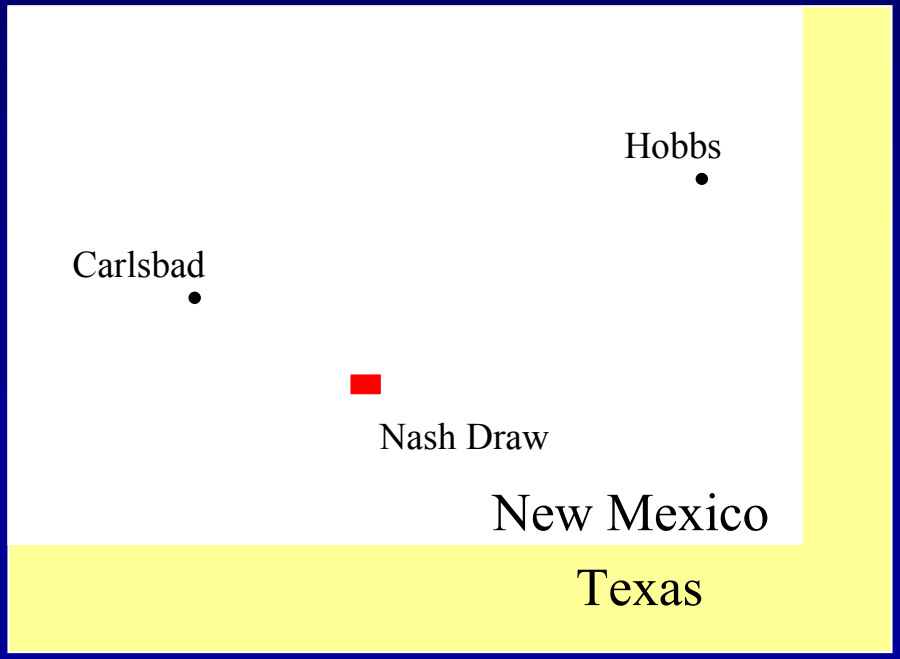
Reservoir simulation mapped the pressure distribution in a potential pilot waterflood area. Seismic results and simulation indicated that the reservoir flow units were limited in size and reservoir pressure was low in the pilot area. Therefore, positive flood response could be anticipated only if gas injection commenced early in the field development.

Strata Production Company

Advanced Oil Recovery Technologies for Improved Recovery from Slope Basin Clastic Reservoirs,

Nash Draw Brushy Canyon Pool,

Eddy County, New Mexico



Outline

- Initial Beliefs & Misconceptions
- Findings of the Study & Reality
- Using Results of the Class III Study

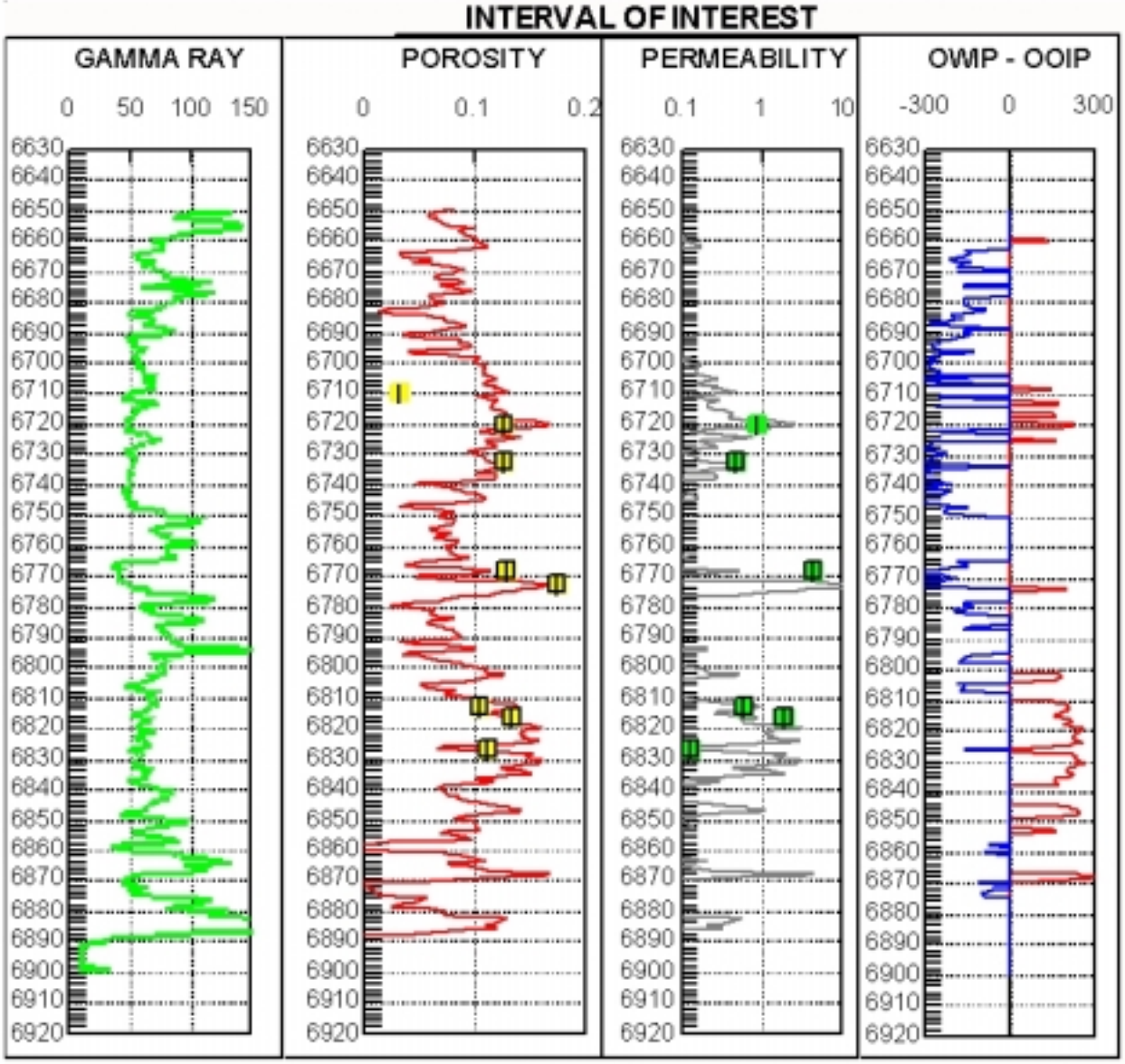
Misconception

- Initial Calculations Suggest Oil Recovery from the Brushy Canyon Reservoir to be about 10% OOIP

Results of the Study

- An **Advanced Log Analysis** Procedure was developed that improved the ability to distinguish productive pay from non-pay
- Oil Recovery from the Brushy Canyon Sandstones is now calculated to be 16.6%
- The Log Analysis Procedure was used to optimize completion/stimulation as well as to identify new productive intervals

TYPICAL BRUSHY CANYON "K" AND "L" ANALYSIS



"K"

"L"

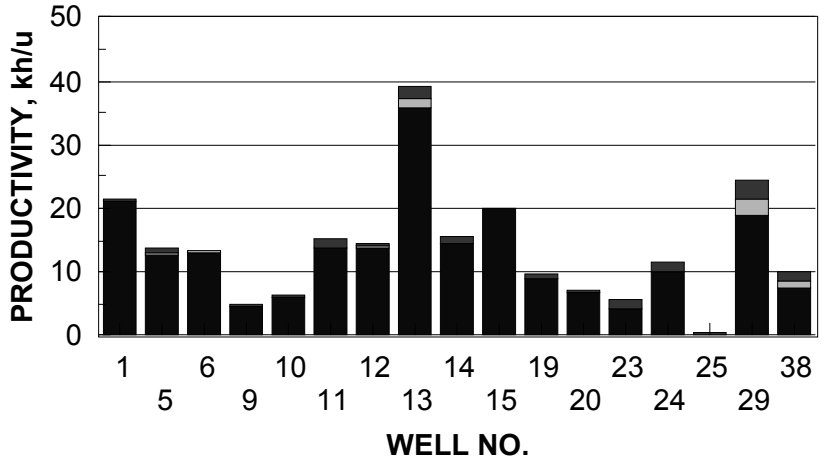
Misconception

- Both the “K” and “L” Sandstones of the Brushy Canyon Interval Were Major Oil Producing Zones

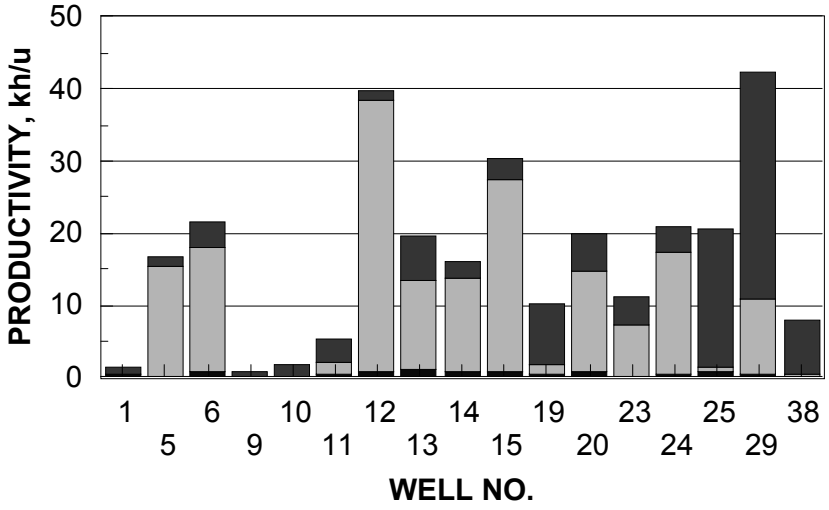
Results of the Study

- Approximately 90% of the Oil Produced at the Nash Draw Pool is from the “L” Zone
- However, Most of the Water is Produced from the “K” and “K-2” Sandstones, if the latter zone is present
- Based on These Results, Well Completions Were Altered

OIL PRODUCTIVITY

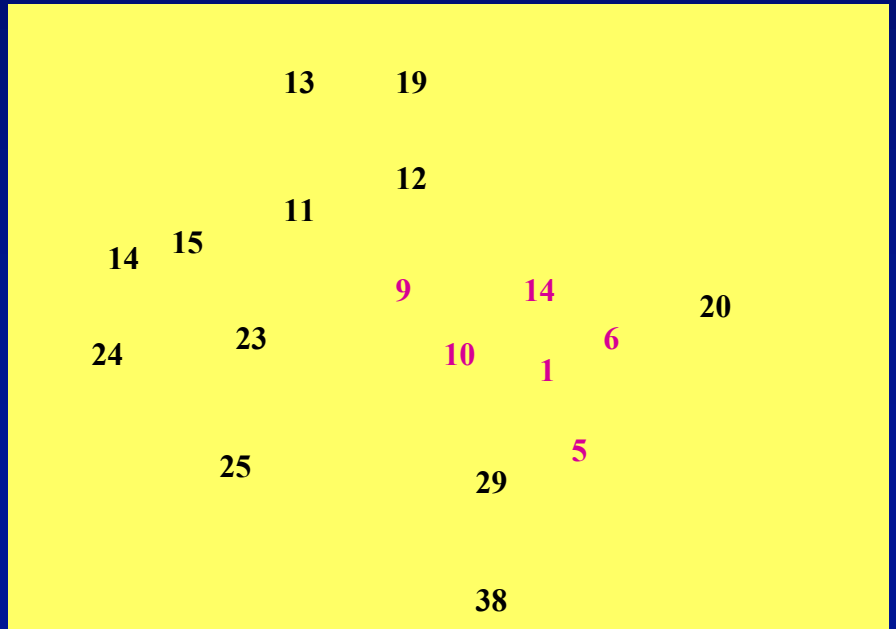


WATER PRODUCTIVITY



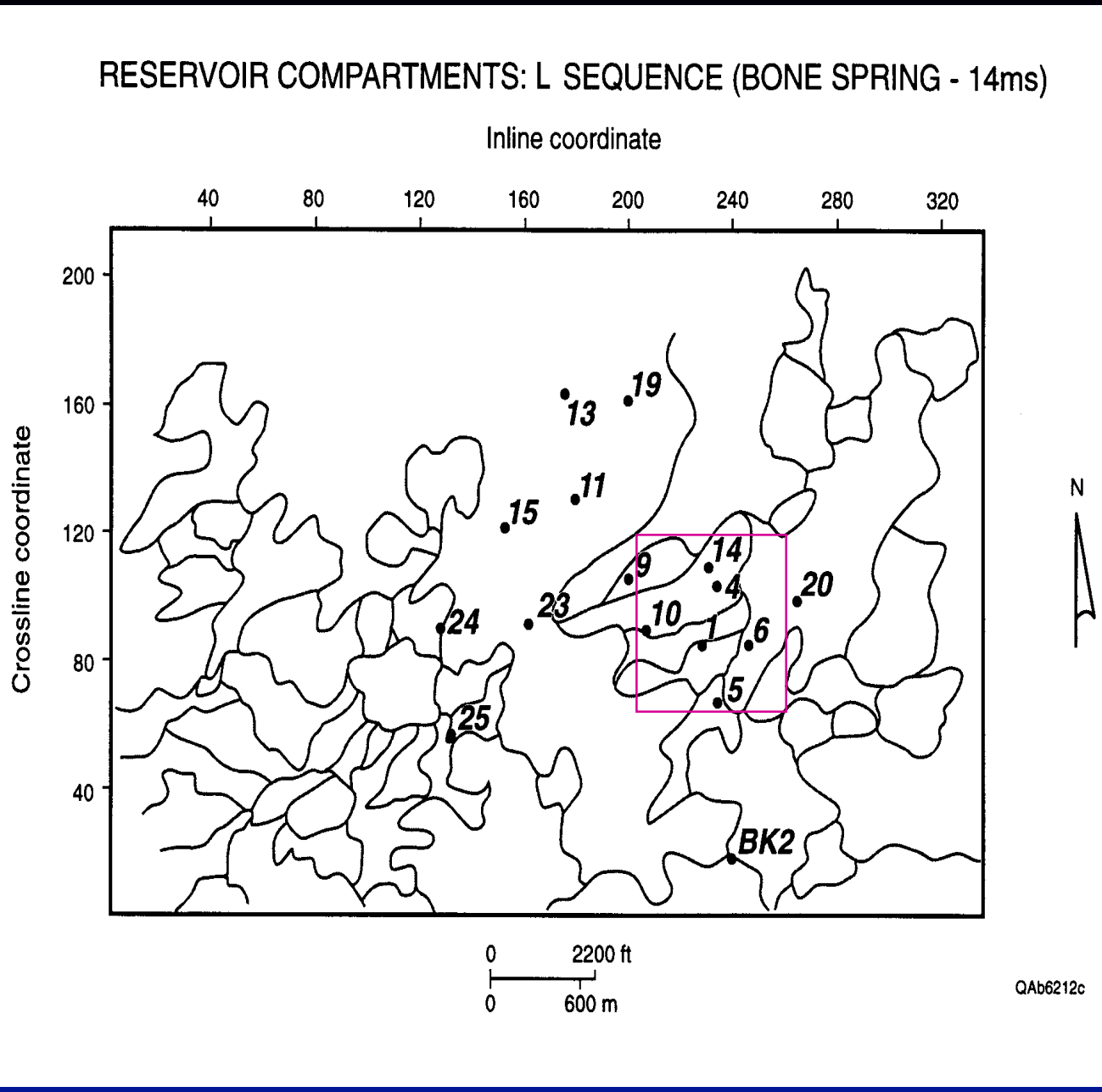
Misconception

- A Pilot Waterflood Could Be Evaluated in a Developed Portion of the Nash Draw Pool and, If Successful, Could Be Expanded Fieldwide



Results of the Study

- Reservoir Simulation results suggest that low permeabilities would dictate gas injection, but the pilot area was pressure depleted & oil recoveries would be low
- Interpretation of the 3D Seismic & other data indicates that the pilot area was very compartmentalized & some sands were not continuous from Well to Well


RESERVOIR COMPARTMENTS: L SEQUENCE (BONE SPRING - 14ms)
Inline coordinate
40
80
120
160
200
240
280
320
Crossline coordinate
200
160
120
80
40
13
19
11
15
9
14
4
20
23
10
1
6
24
5
25
BK2
N
0
2200 ft
0
600 m
QAb6212c

Using Results of the Study

- Improved Completions Strategies
- Targeted Infill Drilling & Extended Reach Drilling
- Plans for Early Implementation of Pressure Maintenance/Gas Injection

Log Anaysis Input Page Well #19

IIIE CORE CALIBRATED LOG ANALYSIS FOR SANDSTONE RESERVOIRS V

WITH MODIFIED X-PLOT POROSITY CALCULATION 6-4-97

WELL INFORMATION

OPERATOR:	Strata Production Company
WELL NO.:	Nash Unit #19
FORMATION:	Nash Draw Delaware
LOCATION:	SECTION 12-T23S-R29E SW/NE
COUNTY:	Eddy
STATE:	New Mexico
DATE:	16-MARCH-1999

OUTPUT

ORIGINAL-OIL-IN-PLACE=	610,299	BBLS.
RECOVERABLE OIL =	101,920	BBLS.
	37	FEET
ORIGINAL-GAS-IN-PLACE=	488,239	MCFG
ORIGINAL-WATER-IN-PLACE=	5,203,433	BBLS.
RECOVERABLE WATER =	868,973	BBLS.

CALIBRATIC	INPUT		OUTPUT
Rt-corr=	1.10	POROSITY=	14.35%
DEPTH =	3903	Sw=	51.00%

ENTER DEPTH OF A KNOWN PRODUCING ZONE, THEN ADJUST Rt CORRECTION FACTOR TO ACHIEVE CORRECT Sw VALUE

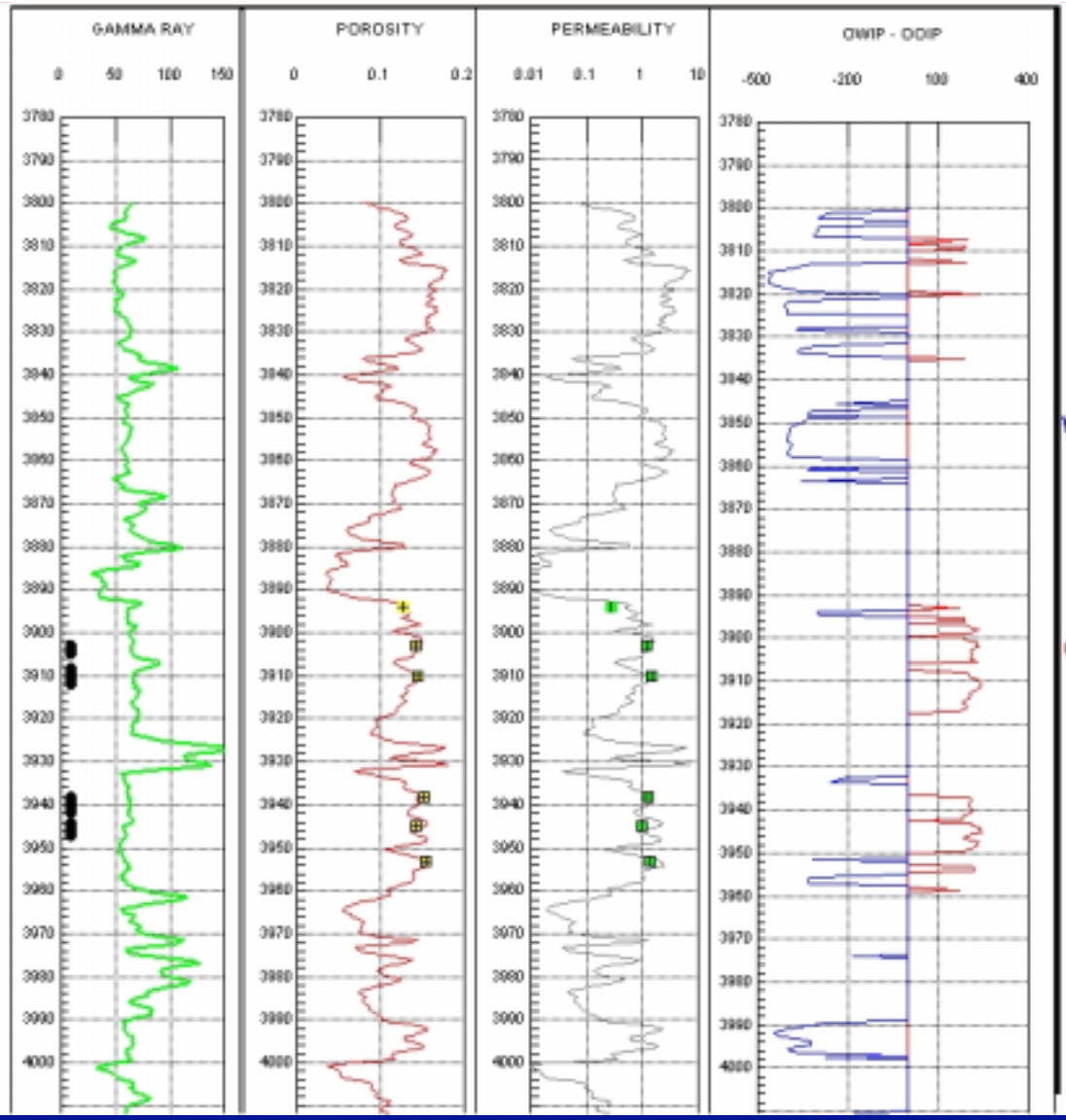
INPUT

MEASURED BHT=	130	F	
BHT DEPTH =	7200	FT.	
AMBIENT TEMPERATURE=	60	F	
INTERVAL TO BE CALCULATED=	3800	TO	4200
TEMPERATURE GRADIENT=	0.9722	F/100 FEET	
VISCOSITY OF RESERVOIR FLUIDS OIL, cp =	0.6	WATER, cp =	0.8
ESTIMATED Rlls =	0.0449		
DELAWARE Rw=	0.047	@ 70 F	
DELAWARE Rw=	0.05	@ 75 F	
PERMEABILITY TYPE=	1	TITE=1, HIGH=2, MED=3, MARGINAL=4	
CORE CALIBRATED PERMEABILITY FACTOR=	1.00		
MEASURED Rmf=	0.103	@ 75F	
CALCULATED @ 75 F	0.053	@ 75 F	
CORE CALIBRATED POROSITY FACTOR=	0.85		
Bg, OIL FORMATION VOLUME FACTOR=	1.30	RES. BBL/STB	
DRAINAGE AREA =	40	ACRES	
Rt-corr CORRECTION FACTOR =	1.10		
CUTOFF RESIDUAL OIL SATURATION =	20.00%		
ESTIMATED RECOVERY FACTOR=	16.70%		
ORIGINAL GOR=	800	SCFG/BO	

CUTOFF VALUES

MAXIMUM Sw VALUE =	55.00%	
MINIMUM POROSITY - OIL ZONES =	12.00%	
MINIMUM POROSITY - WATER ZONES =	8.00%	
MAXIMUM GAMMA RAY VALUE =	75	API UNITS

Output for Well #19



PERMEABILITY MATCH INDICATES ROCK TYPE #1 -VERY FINE GRAINED

Wet Zone

Oil Zone

Log Analysis Input Page For Well #24

IIIE CORE CALIBRATED LOG ANALYSIS FOR SANDSTONE RESERVOIRS V

WITH MODIFIED X-PLOT POROSITY CALCULATION 6-4-97

WELL INFORMATION

OPERATOR:	Strata Production Company
WELL NO.:	Nash Unit #24
FORMATION:	Nash Draw Delaware
LOCATION:	SECTION 14-T23S-R29E SE/NE
COUNTY:	Eddy
STATE:	New Mexico
DATE:	16-MARCH-1999

OUTPUT

ORIGINAL-OIL-IN-PLACE=	113,544	BBLS.
RECOVERABLE OIL =	18,962	BBLS.
	5	FEET
ORIGINAL-GAS-IN-PLACE=	90,835	MCFG
ORIGINAL-WATER-IN-PLACE=	6,415,637	BBLS.
RECOVERABLE WATER =	1,071,411	BBLS.

CALIBRATIC	INPUT		OUTPUT
Rt-corr=	1.10	POROSITY=	19.91%
DEPTH =	4178	Sw=	67.15%

ENTER DEPTH OF A KNOWN PRODUCING ZONE, THEN ADJUST RI CORRECTION FACTOR TO ACHIEVE CORRECT Sw VALUE

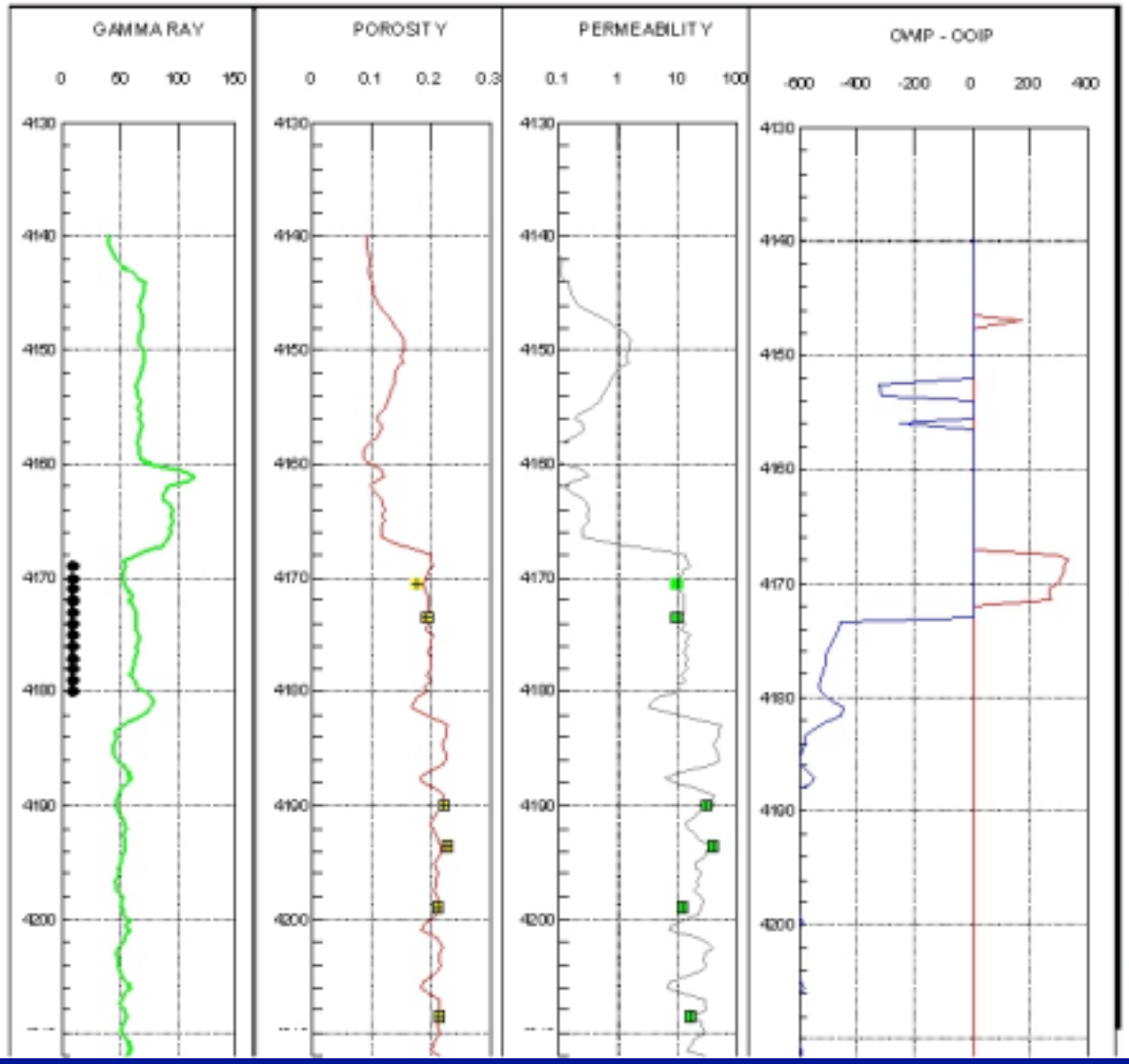
INPUT

MEASURED BHT=	130	F	
BHT DEPTH=	7200	FT.	
AMBIENT TEMPERATURE=	60	F	
INTERVAL TO BE CALCULATED=	4140	TO	4300
TEMPERATURE GRADIENT=	0.9722	F/100 FEET	
VISCOSITY OF RESERVOIR FLUIDS OIL, cp =	0.6	WATER, cp =	0.8
ESTIMATED Rlls=	0.0411		
DELAWARE Rw=	0.047	@ 70 F	
DELAWARE Rw=	0.05	@ 75 F	
PERMEABILITY TYPE=	1	TITE=1, HIGH=2, MED.=3, MANUAL=4	
CORE CALIBRATED PERMEABILITY FACTOR=	0.80		
MEASURED Rmf=	0.103	@ 75F	
CALCULATED @ 75 F	0.05	@ 75 F	
CORE CALIBRATED POROSITY FACTOR=	0.95		
Bg, OIL FORMATION VOLUME FACTOR=	1.30	RES. BBL/STB	
DRAINAGE AREA =	40	ACRES	
Rt-corr CORRECTION FACTOR =	1.10		
CUTOFF RESIDUAL OIL SATURATION =	20.00%		
ESTIMATED RECOVERY FACTOR=	16.70%		
ORIGINAL GOR=	800	SCFG/BO	

CUTOFF VALUES

MAXIMUM Sw VALUE =	55.00%	
MINIMUM POROSITY - OIL ZONES =	12.00%	
MINIMUM POROSITY - WATER ZONES =	8.00%	
MAXIMUM GAMMA RAY VALUE =	75	API UNITS

Output for Well #24



TYPE 1 SAND -VERY FINE GRAIN

OIL ZONE

INCREASING WATER SATURATIONS WITH DEPTH

PREDICTED
20 BOPD & 150 BWPD

ACTUAL
20 BOPD & 120 BWPD

WET ZONE

Increased Reserves

Well #	Zones	Reserves, BOE	A.F.E. Estimated Cost	Development Cost, $/BOE
13	“H”, “E” & “C-2”	80,325	$84,593	$1.05
15	“H-4”, “G-3” & “F-3”	47,514	$75,114	$1.58
19	“J” & Bell Canyon-Lower	95,163	$91,942	$0.97
24	“F-3”, “F-2”, “D” & “CC-2”	66,944	$96,676	$1.44
	Total	**289,946**	**$348,325**	**$1.20**

Initial Incremental Production

Well #	Incremental Oil BOPD	Incremental Gas MCFGD	Incremental Water BWPD
13	29	24	146
15	12	10	88
19	12	22	173
24	28	165	120
Total	**81**	**221**	**527**

Targeted Drilling

- Geostatistical Analysis for Spatial Distribution of Reservoir Properties
- Reservoir Simulation to Assess Reservoir Pressure Throughout the NDP
- Multivariable Seismic Attribute Analysis
  - Interwell Reservoir Properties
  - Extrapolate to Regions Beyond Well Control

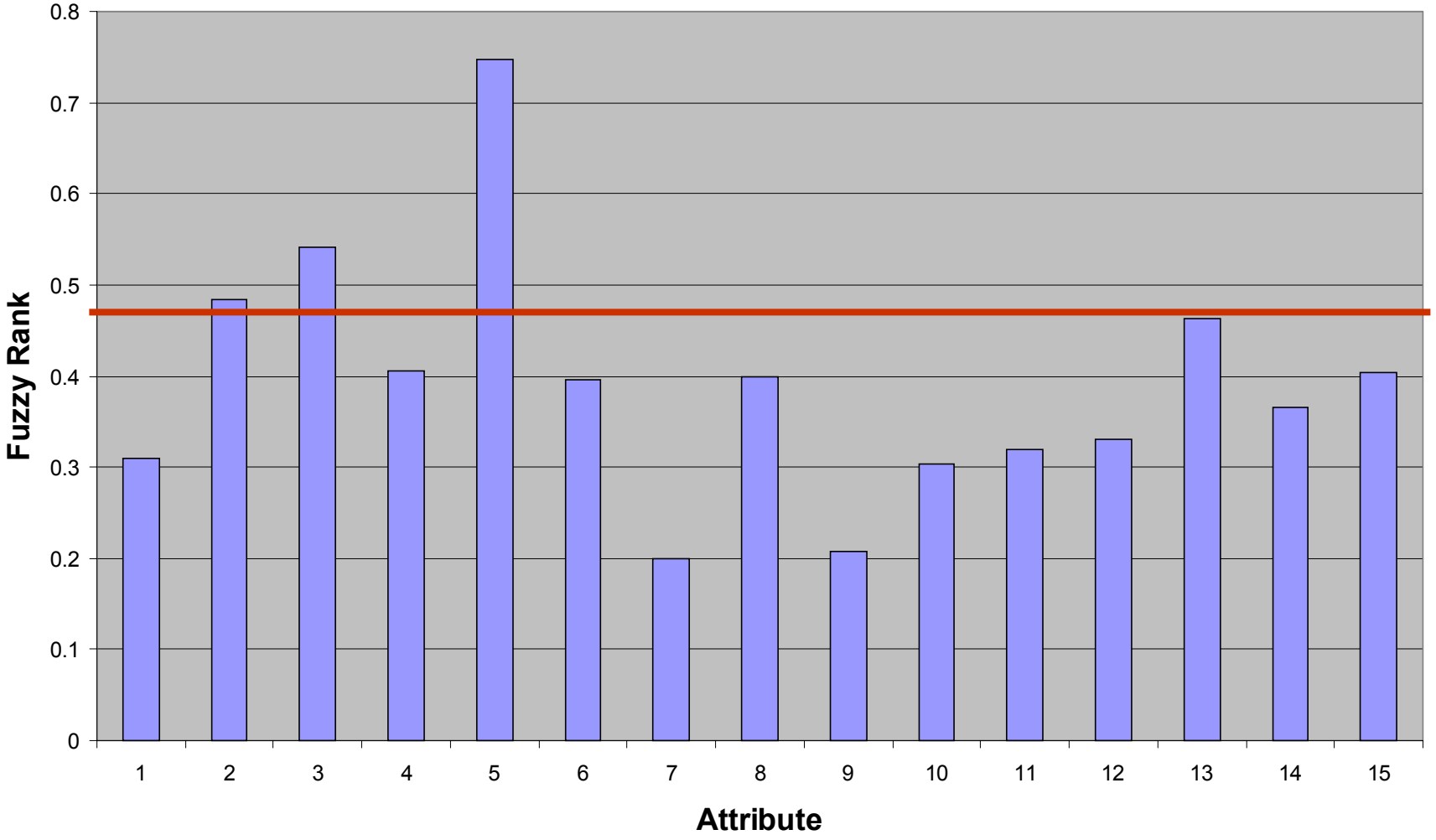
Geostatistical Analysis

- Log data used to map HCPV
- Results were similar with 3 techniques (nearest-neighbor, kriging algorithm, and a fractal model) and confirmed drilling targets
- Geostatistics interpolates--extrapolation of properties was needed

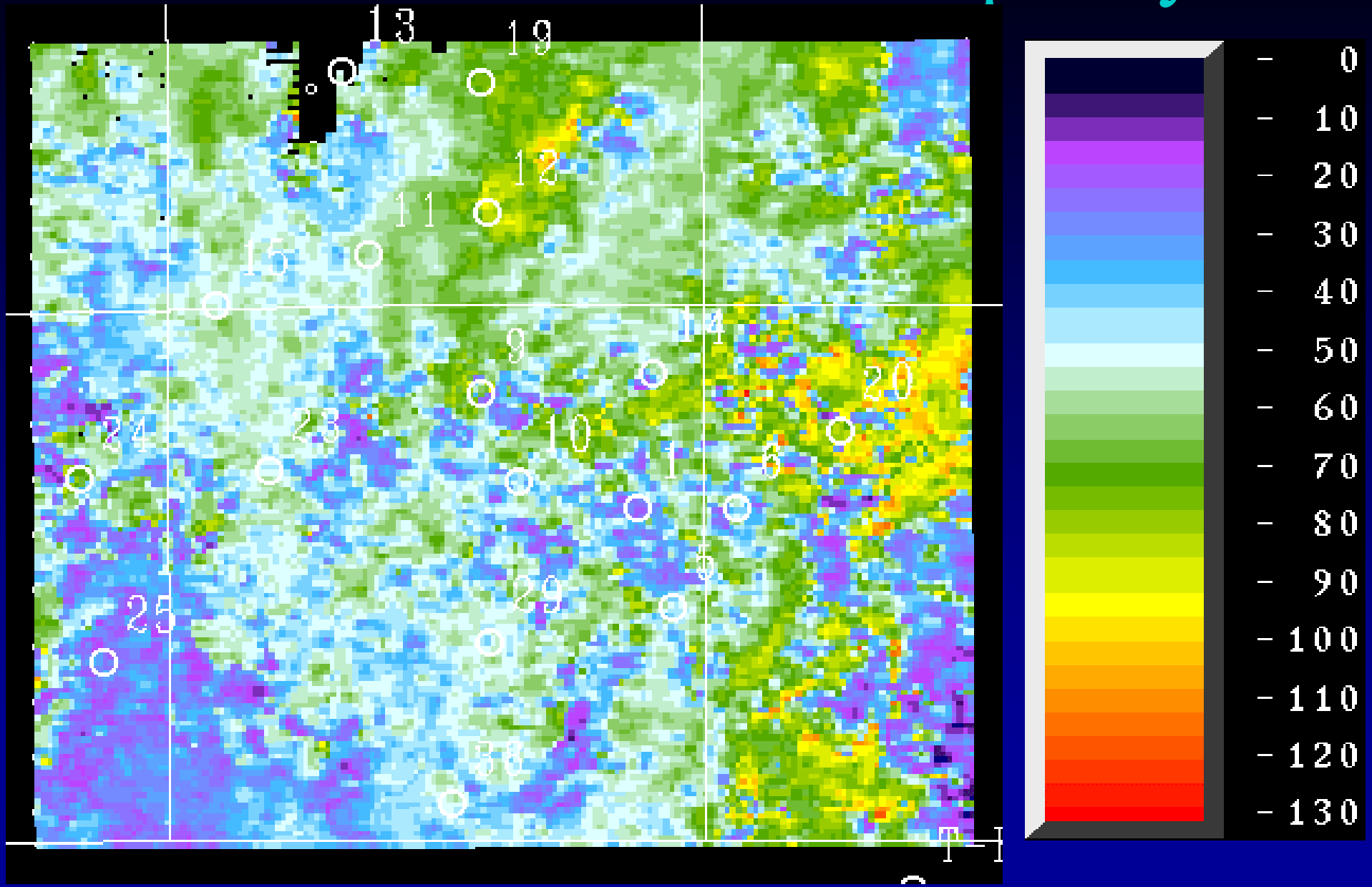
Pattern Recognition

- Fuzzy Logic or Fuzzy Ranking used statistics to decide which seismic attributes provide the best correlation with reservoir properties (porosity, net pay, and water saturation)
- Neural Networks trained to fit non-linear multi-variable relationships between input data and desired parameters

Fuzzy Ranking of Attributes for Correlating to Average L Interval Porosity

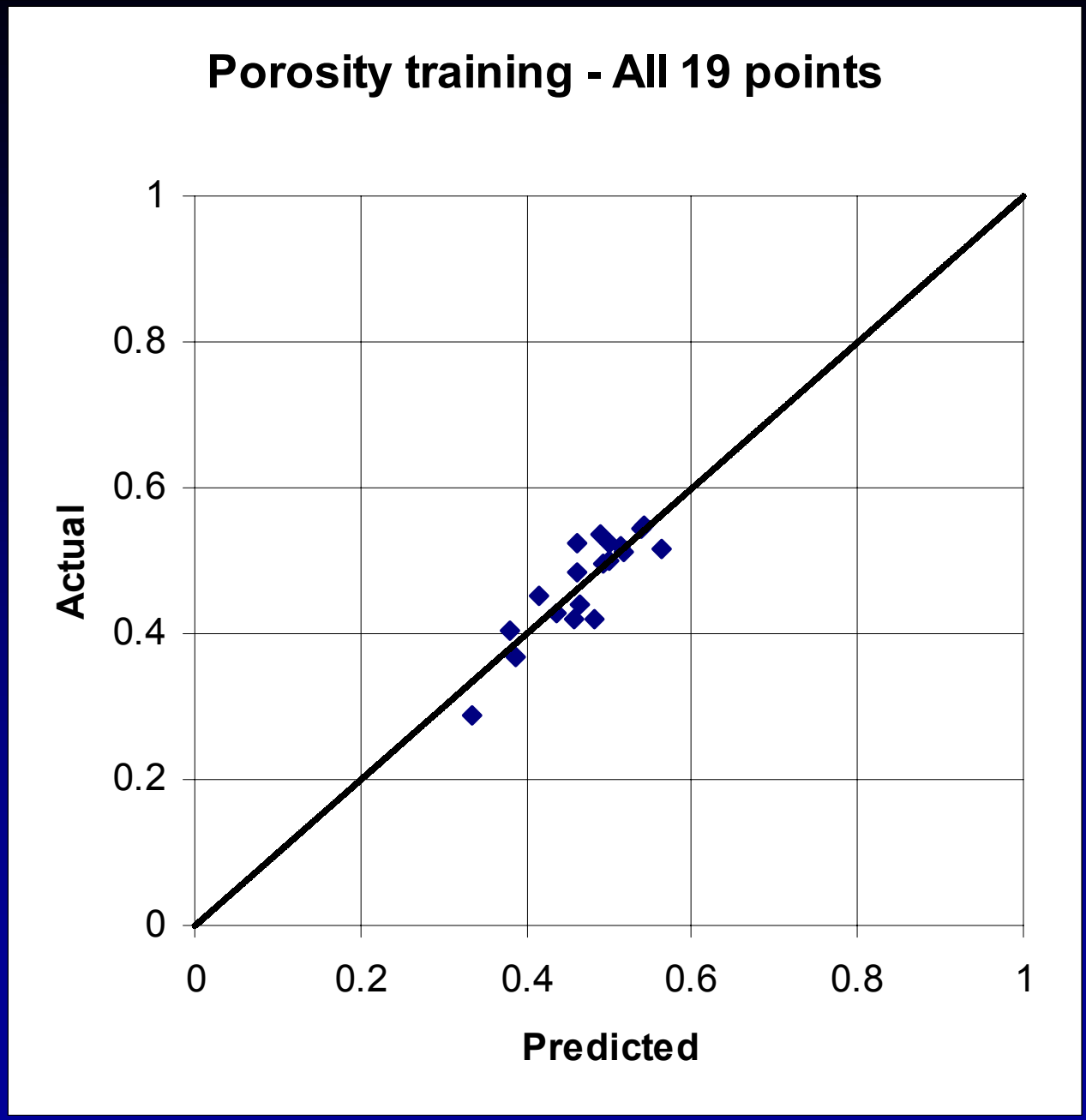


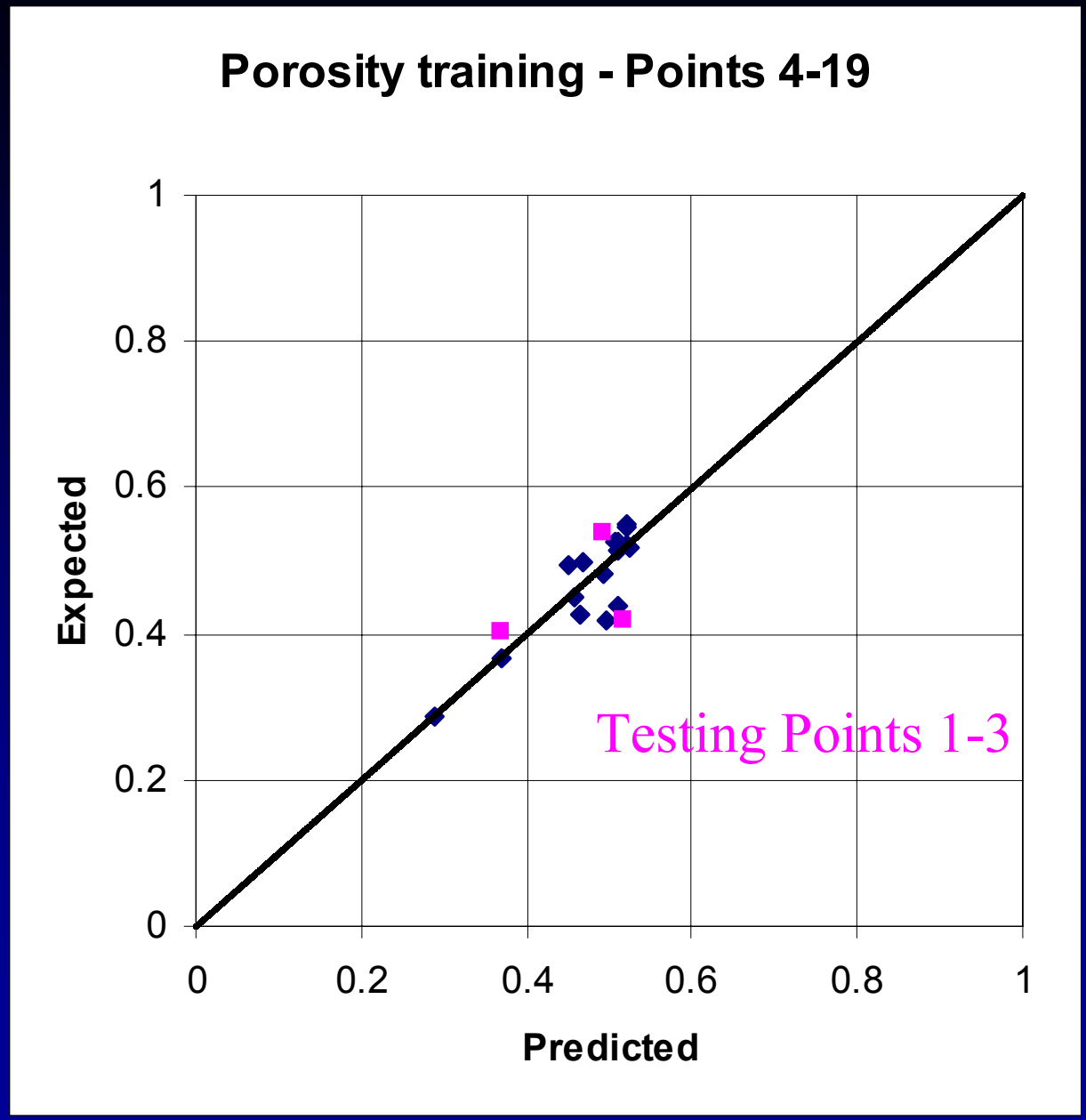
L Ave Instantaneous Frequency

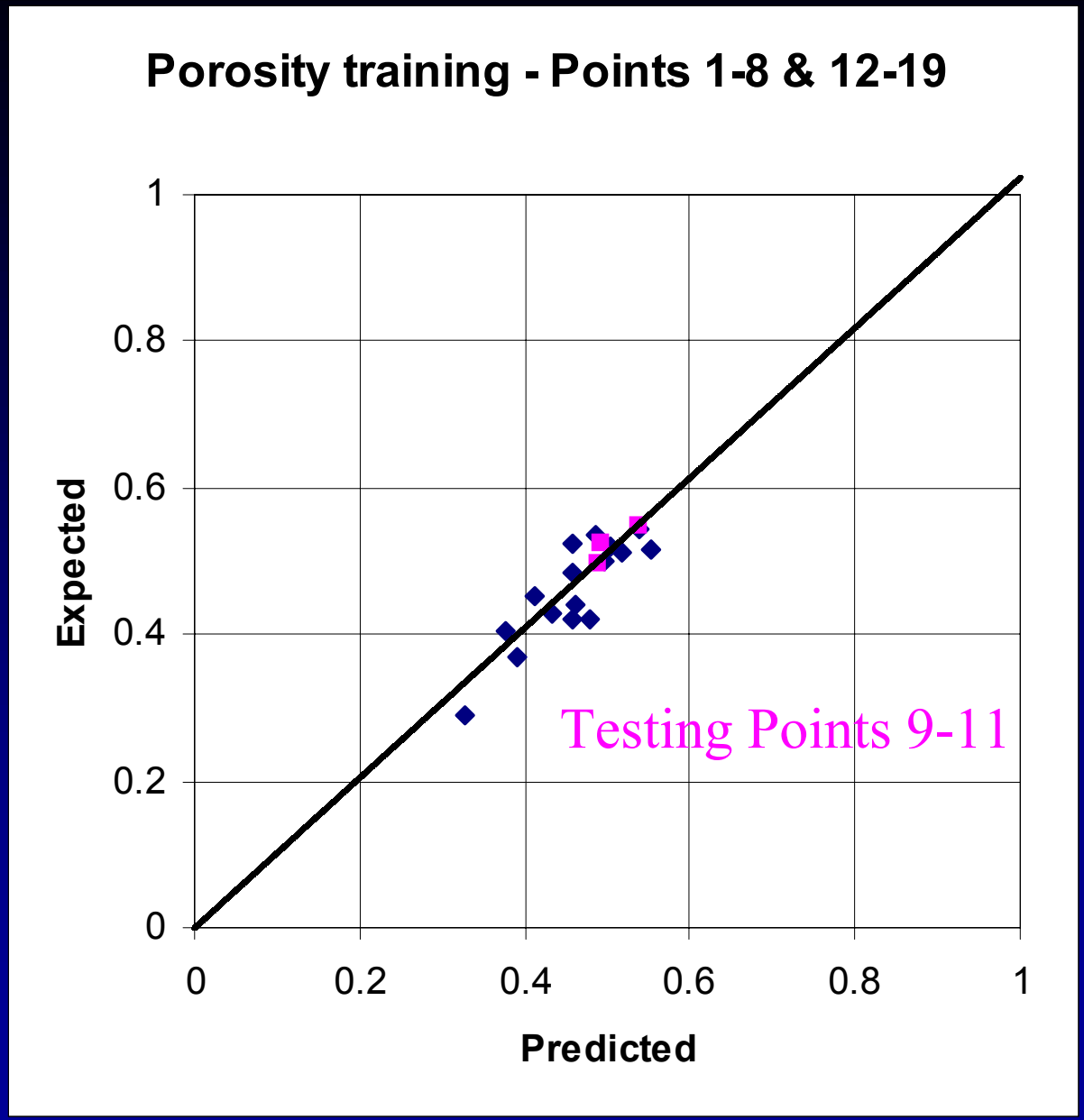


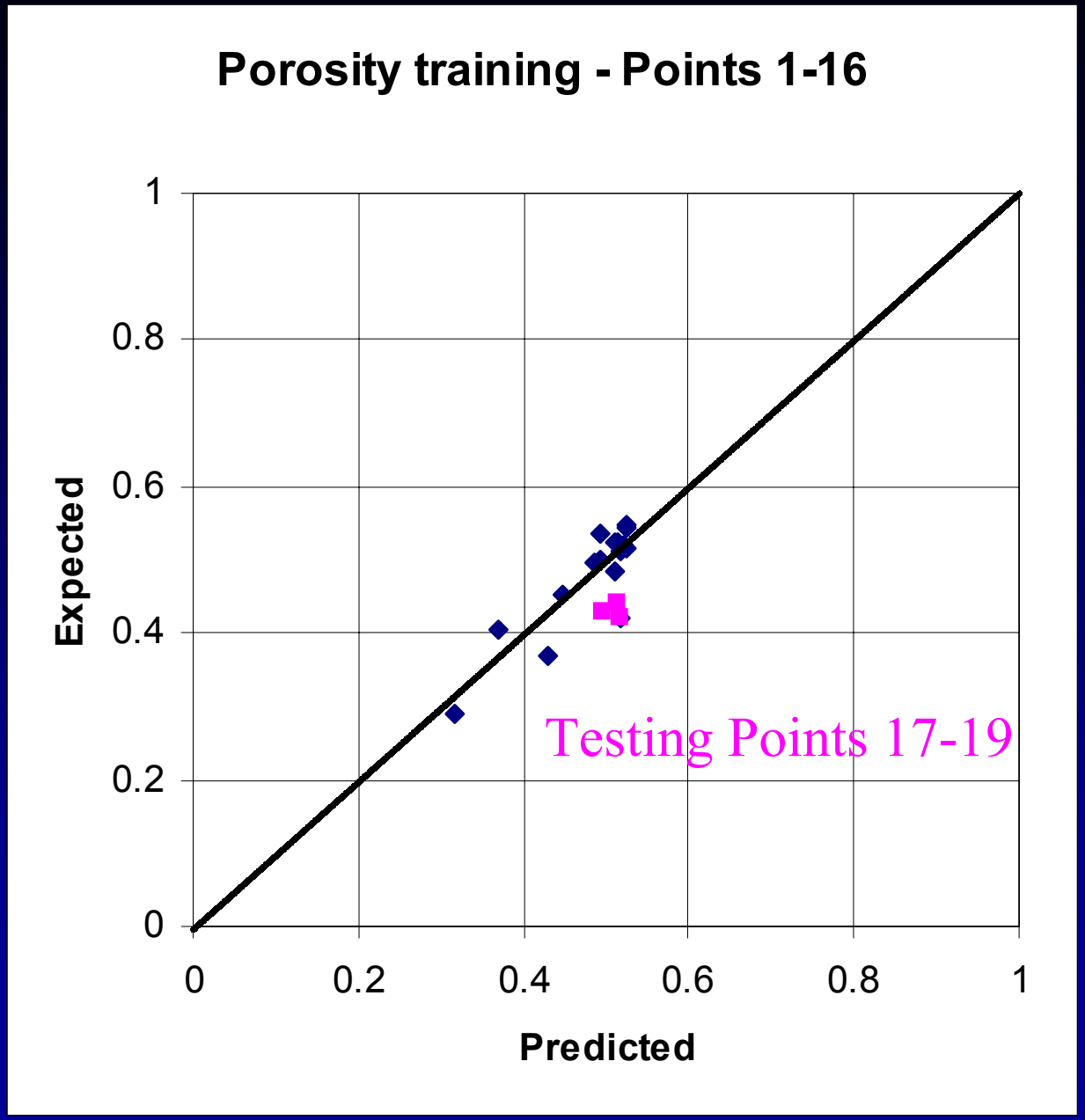
Predicting Interwell Data

- Neural Networks were trained to evaluate ϕ, Sw, and net pay using seismic attributes extracted from the "L" zone
- Well data averaged across that interval to guide the training algorithms
- Several data were removed and the Networks were retrained to test how well the Network can predict interwell data

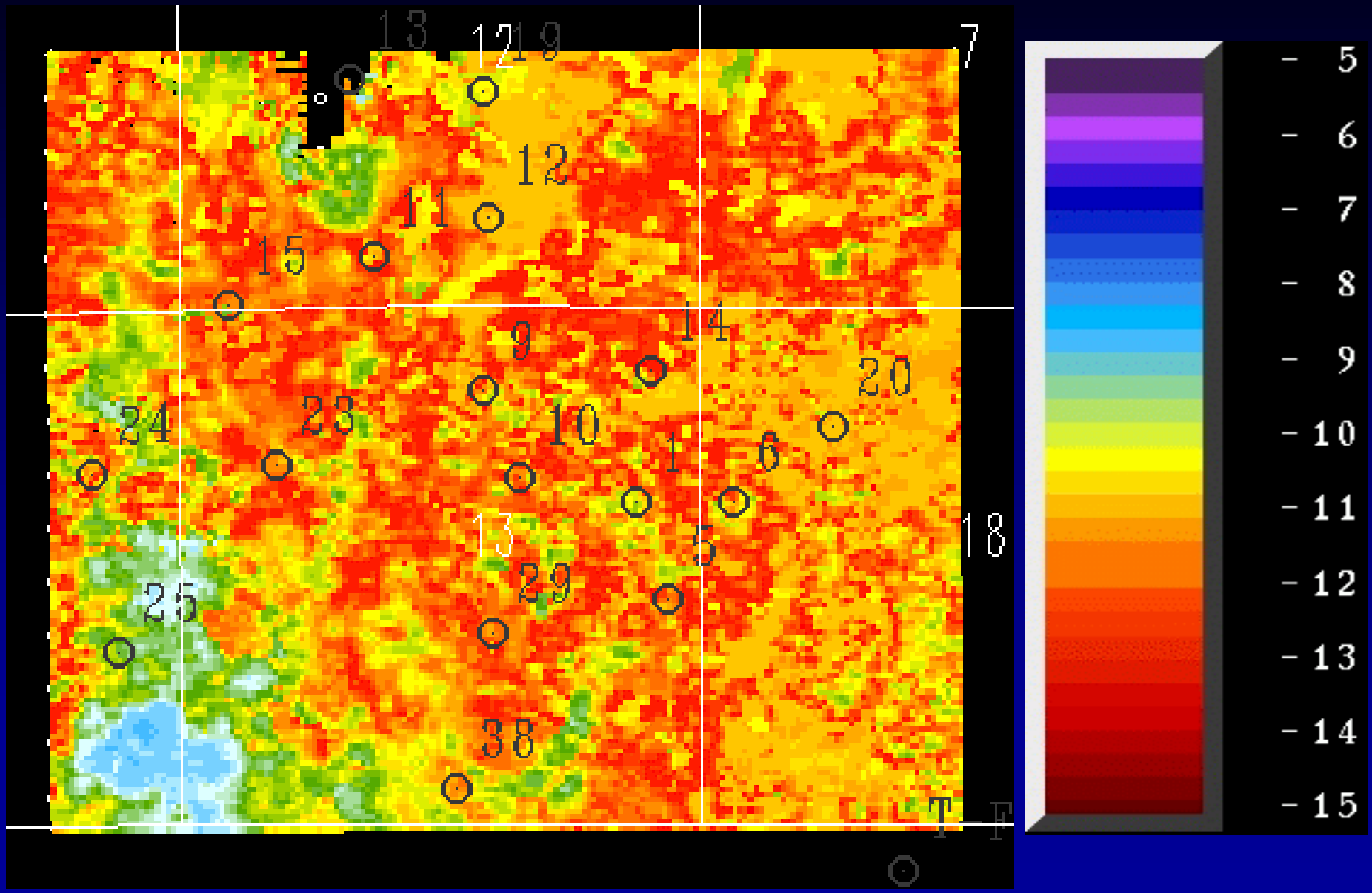

Porosity training - All 19 points
Actual
Predicted
0
0.2
0.4
0.6
0.8
1


Porosity training - Points 4-19
Expected
Predicted
0
0.2
0.4
0.6
0.8
1
Testing Points 1-3

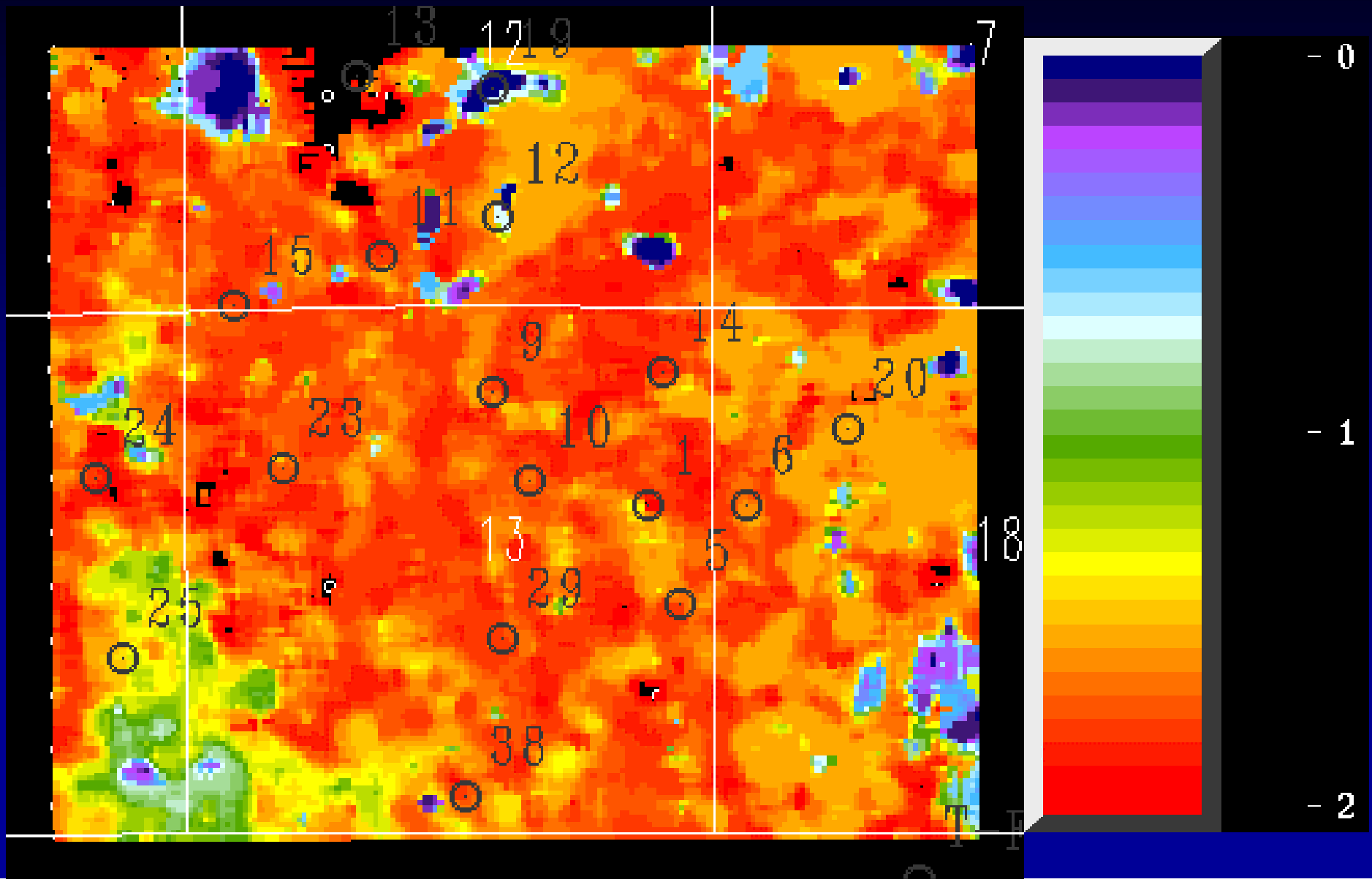

Porosity training - Points 1-8 & 12-19
Expected
Predicted
0
0.2
0.4
0.6
0.8
1
Testing Points 9-11


Porosity training - Points 1-16
Expected
Predicted
0
0.2
0.4
0.6
0.8
1
Testing Points 17-19

Predicted L ϕ



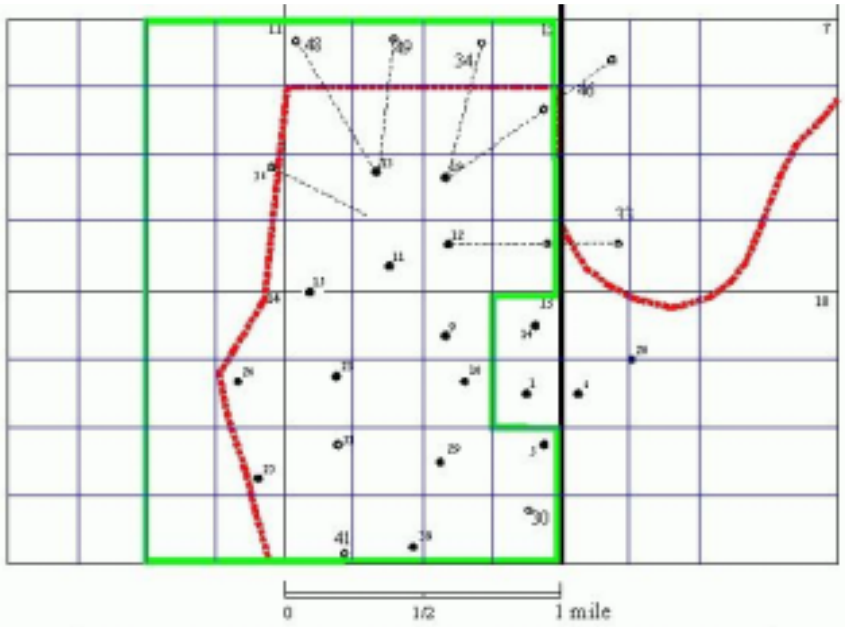
Predicted L hϕSo



Seismic Attribute Findings

- Fuzzy Ranking can help decide which seismic attributes are most useful for evaluating reservoir properties
- Multivariable non-linear regression (Neural Networks) can be used to correlate well and seismic data
- Predictions of interwell reservoir properties are feasible--extrapolation is possible

Directional/Horizontal Wells to develop areas under the potash area and playa lakes



NASH DRAW UNIT

EDDY COUNTY, NM

T23S-R29E & T23S-R30E

Potash Boundary

Farmout Area

Project Status

- A proposed pressure maintenance injection in Phase I was not conducted because the pilot area was pressure depleted, and seismic results suggest compartmentalization
- In Phase II, a pilot injection test will be reconsidered in a more continuous part of the NDP if such areas have sufficient reservoir pressure

Project Status

- To develop better areas of the field located under playa lakes and potash mining, deviated/horizontal wells will be drilled in Phase II-- Initially 3 wells to evaluate:
  - Drilling & completion techniques
  - Ability of the seismic attribute analysis to identify high quality targets
- Additional development wells